4.0 CITY OF FORKS MUNICIPAL WATER SUPPLY

The City of Forks (City) is located in western Clallam County, near the confluence of the Sol Duc, Calawah and Bogachiel Rivers on the Olympic Peninsula of western Washington (Figures 1-1 and 4-1). Forks is the largest community in WRIA 20 with a water service population of approximately 5,000, including the incorporated city limits and surrounding unincorporated area. The City serves water to over half of the population of the watershed with groundwater from their municipal water supply.

Information on the City's water system was reviewed as a component of the WRIA 20 Storage Assessment in order to assist the City in providing a safe and reliable source of drinking water. The information contained in this chapter will help in the planning of the City's municipal water supply needs, which is one objective of the watershed planning.

4.1 Hydrogeology

Groundwater in the Forks Prairie area is mainly found in glacial sediments, therefore understanding the glacial geology of the region is important for determining many factors, including groundwater recharge, discharge and movement, as well as any hydraulic connection between groundwater and surface water. The extent of glaciation is important to the hydrogeology of an area because the presence of till (deposited at the base of a glacier) often results in confining units which can control the recharge and flow of water in an aquifer. There are reports that the ice may have been up to 2,000 feet thick in the Quillayute-Forks area (Booth and Goldstein, 1994).

4.1.1 Glacial Deposition

Two main types of glaciers are alpine (valley) and continental (ice sheet). Alpine glaciers are bodies of ice originating in mountainous areas and flowing downvalley to their terminus. A typical alpine glacier might cover several square miles and reach thicknesses of several hundred feet. Ice sheets are much larger, covering hundreds to thousands of square miles with ice thickness up to thousands of feet. While alpine glaciers are usually restricted to alpine valleys, ice sheets are thick enough to move over existing terrain.

The continental glacier which flowed into the western United States during the last ice age is called the Cordilleran Ice Sheet. The Cordilleran Ice Sheet advanced from Canada into western Washington between 1 million years ago and retreated approximately 12,000 years ago. The Puget Lobe of the ice sheet occupied Puget Sound between the Cascade Range and Olympic Mountains. West of the Puget Sound, the Cordilleran Ice Sheet advanced into the Straight of Juan de Fuca, along the northern edge of the Olympic Mountains, wrapping slightly southward around the western tip of the Olympic Peninsula to near the present-day location of the City of Forks. Geologic mapping indicates the north and west sides of the Olympic Peninsula are covered with a blanket of glacial deposits derived from the last major advance of the Cordilleran Ice Sheet (Tabor and Cady, 1978).

In addition to the continental glaciers, smaller alpine glaciers also strongly influenced this region of WRIA 20. Today the Olympic Mountains harbor 266 active alpine glaciers. Most are cirque glaciers, but several small valley glaciers extend beyond the cirques (Spicer, 1986). Despite the relatively small size of most of the alpine glaciers in the Olympic Mountains today, the sedimentary record of many valleys of the Peninsula indicate a history of much more extensive glacial activity. Geologic mapping indicates that some valleys in the western Olympics repeatedly hosted large Pleistocene valley glaciers, whereas other valleys had only limited glacial activity in their headwaters, or glaciers were absent altogether (Montgomery, 2002). Glaciation, sea level fluctuation and tectonic deformation were the main governing forces in the Quaternary history of Olympic Peninsula, but glaciogenic deposition has exerted the dominant influence on geomorphic and stratigraphic evolution of the river valleys (Thackray, 1996). In the western Olympic Peninsula, for instance glaciated valleys are thought to have had between two and four times as much rock mass removed from them as fluvial valleys (Montgomery 2002).

The hydrogeology of the Forks Prairie area is complicated by fact that there were numerous glacial advances into the western Olympic Peninsula. The glacial record of the western Olympic Peninsula is unique because it records a time of limited alpine ice extent during the last maximum extent of continental glaciers. The Queets and Hoh river valleys contain morphologic and stratigraphic evidence of at least six ice advances during the last (Wisconsin) glacial cycle (Thackray, 2001). It has been assumed that mountain glaciers fluctuate synchronously with continental ice sheets. However, the glacial sediment record indicates that the maximum advance of the alpine glaciers of the Olympic Peninsula preceded the maximum advance of the Cordilleran Ice Sheet by as much as 8,000 years (Thackray 2001). The smaller mass of alpine glaciers typically allows more rapid response to short-lived regional climatic fluctuations than continental ice sheets. However this has been difficult to document because many mountain glacier records in the western United States are incomplete due to a lack of datable material, poor stratigraphic exposure and/or erosion or concealment as a result of the extensive advances during the last glacial maximum (Thackray, 2001). Alpine glaciation in the Olympic Mountains appears to have been driven mainly by moisture supply from the Pacific Ocean and not necessarily by periods of coldest temperatures. Moisture supply to the Olympic mountains during the last glacial maximum was hindered by changes in regional weather patterns (e.g., a southern shift in the winter jet stream) thought to have been caused by the presence of the Cordilleran Ice Sheet (Thackray, 2001). The apparent differences in the timing of alpine and continental glacier fluctuations may also be the result of the contrasting preservation of sedimentological record.

We speculate that alpine glaciation in the Calawah River basin may not have been as extensive as other areas in the western Olympics (e.g., Queets and Hoh) because the elevation in the catchment is generally below 4,000 feet. The topography of the South Fork of the Calawah River and the Sitkum River do not indicate the strong "U-shaped" topography typically present in glaciated valleys. The North Fork of the Calawah River may have had a much stronger influence.

4.1.2 Post-Glacial Processes and Contemporary Hydrogeology

This section includes discussion of the post-glacial processes that formed today's landscape, along with a relatively detailed discussion of groundwater flow in the Quillayute Prairie area. More detailed discussion of groundwater flow in the Forks area is contained within the section in which groundwater flow and wellhead protection areas are modeled.

According to the "hardpan" (as till is often referred to by well drillers) indicated in well logs for the City's wells, the continental ice sheet advanced into the Forks Prairie area (likely from the north along the present-day location of Highway 101). Till likely blanketed the entire area from Forks Prairie to Quillayute Prairie and locations further south and west. Water from the ancestral Calawah, Sol Duc and Bogachiel Rivers likely eroded and reworked the material deposited by the glacier, and may have deposited the sand and gravel unit in which the City's wells are completed. In the process of reworking the sediments deposited by the ice sheet, water draining from the Calawah River and other drainage basins likely eroded the till plain from its former position of occupying the valley into its current configuration (Figure 4-2).

Field visits were conducted to confirm previously mapped lithologies (Appendix 4-A). One cross section was developed along the east-west axis of the Quillayute System (Figure 4-3), along with three north-south cross sections (Figures 4-4 through 4-6).

The Quillayute Prairie is home to a few dozen residences and the Quillayute State Airport. The Airport was constructed in the early 1940s and used as a military airbase during World War II. While the military installation was active, it had a population of approximately 2,000 and was supplied with water from three wells. The Airport is now owned and operated by the City of Forks.

The Quillayute Prairie is a gently sloping terrace located between the Dickey and Sol Duc Rivers (Figures 4-4 and 4-5). The Prairie is comprised of till (compacted, poorly sorted clay, silt, sand, gravel and cobbles) which is over 80 to 100 feet thick, according to well logs for wells completed in the area and conditions observed in the field (Appendix 4-A). The southern edge of the prairie is abruptly truncated and forms a bluff overlooking the broad floodplain of the Sol Duc River.

The Quillayute Prairie is likely a remnant of the larger till layer, which was eroded by the Sol Duc and Dickey Rivers that left an “island” forming the prairie. The linear, northeast-southwest trending ridge located between the Calawah River and Quillayute Road (north of Forks; mapped as undifferentiated drift in Figure 4-1) is also capped by till (Figures 4-6). This linear hill is also likely a remnant of a continuous till sheet that was eroded leaving this island of till.

Using geologic and topographic maps and limited water level data, a conceptual model of groundwater flow was developed for the Quillayute Prairie area. Water levels were measured in several wells using an electronic water level sounder. Wellhead elevations were recorded with a handheld GPS unit. (The accuracy of GPS unit varied between ±18 and 23 feet and may produce inexact groundwater elevations). Groundwater elevations on Quillayute Prairie likely approximate topography and there appears to be a main groundwater divide along the axis of the prairie that might be coincident with the “east-west” runway of the Airport. Groundwater flow beneath the Airport is likely to the north and south off either side of the Prairie from this divide. Wetlands near Quillayute Road (SE ¼ SW ¼ Sec. 13, T 28 N, R 15 W) may be coincidental with groundwater discharge. On the north side of Quillayute Prairie, the small tributary streams of the Dickey River are incised into the Prairie and to which groundwater is draining (Secs. 7 & 13, T 28 N, R 15 W).

Most domestic wells on the Prairie are drilled to depths between 100 and 130 feet and are completed in a sand and gravel layer. The sand and gravel layer supplying water to domestic wells on Quillayute Prairie is likely a separate water bearing layer than the Quileute wells completed in the Three Rivers area (Figure 4-4 and 4-5). Well logs for wells completed in the Three Rivers areas indicate the presence of a clayey sand and gravel unit in the upper 20 to 30 feet of the borings. This unit is likely stratigraphically lower than the sand and gravel unit in which the wells on Quillayute Prairie are completed. Additionally, the water level in the wells on Quillayute Prairie are between 60 and 70 feet higher than the wells completed in the Three Rivers area. According to the conceptual model (Figure 4-2), wells in the Quillayute Prairie area tap older alluvium and outwash, whereas the Quileute wells tap younger alluvium. Hydraulic connection between wells on Quillayute Prairie and the Three Rivers area may be limited, if present at all. In addition to lack of a clear connecting unit between the areas, the Sol Duc River likely acts as a groundwater divide between the two locations.

4.2 Water Supply System

The municipal water system for the City of Forks is presented in this section. A review of water rights and use is first described, followed by a description of the sources of water, water quality considerations and finally conventional infrastructure storage.

4.2.1 Municipal Water Rights and Water Use

The City has three active groundwater rights. The City holds 1,100 gallons per minute (gpm) and 950 acre-feet/year in primary rights for Wells 1, 2, 4 and 5 (Table 4-1). The City's 1999 Comprehensive Water System Plan indicated a total water rights of 1,430 gpm and 950 acre-feet/year (Polaris, 1999). A review of the City's water right files indicated that some of the rights are supplemental (Table 4-1), however the designations are not clearly stated in the water rights files. Despite repeated mention in the water rights files of the portions of the total Qa (annual quantity) being supplemental, there is not an explicit mention regarding the amount of primary Qi (instantaneous quantity). It is assumed that 500 gpm under GWC 2108-A and 600 gpm under G2-24829C are primary, for a total primary Qi of 1,100 gpm. The relative size of these quantities is consistent with municipal water use patterns where the value for Qi (in gpm) is higher than the value for Qa (in acre-feet/year) calculated if the well were pumped continuously. In order to meet peak water demand, municipalities typically must pump at rates higher than those calculated for average Qa use.

In 2004, the City pumped approximately 655 acre-feet of water. Assuming a service population of 5,000, the average per capita water use is 119 gallons per day per person (gpcpd). This per capita use value is slightly higher than values reported for Clallam County by the USGS, where values of 100 gpcpd was reported for domestic use and 103 gpcpd was reported for all uses including domestic, irrigation and industrial uses (Lane, 2004). A full characterization of water use has not been conducted, and factors that may affect calculated per capita use patterns include industrial use.

Average monthly use is shown in Figure 4-7. The average monthly use from November to April is assumed to be representative of non-consumptive interior use and accounts for approximately 90% of the total water use. This water use is considered non-consumptive because it is returned to the groundwater through septic systems, including the treated effluent from the City of Forks wastewater treatment plant. The higher use from May to October is assumed to reflect exterior use (e.g., landscape irrigation). This use is considered to represent consumptive use due to evapotranspiration losses, although a portion of it may recharge to groundwater depending on irrigation patterns.

Total annual water use in 2004 has not changed significantly from 1999 (i.e., approximately 700 AF/yr). Therefore, annual and instantaneous water use projections from the 1999 Comprehensive Water System Plan are used and adjusted assuming no significant change between 1999 and 2005, and assuming future annual demand growth of 1% and 3% (Figures 4-8 and 4-9). This results in the need for additional water rights within the next few years as driven by the need to meet maximum daily demand estimates (e.g., instantaneous). This estimate is based on an assumed maximum daily demand peaking factor of 2.5 and an associated maximum average daily demand of slightly less than 1,100 gpm (Polaris, 1999). This factor may be conservatively large, given that the actual maximum installed pumping capacity is approximately 880 gpm. Conservative estimates are standard in water system planning to provide a safety margin. The City currently records water use on analog spiral chart recorders, which makes review of the data labor intensive. Replacement with digital recorders, as is planned in the near future, will facilitate data analysis.

The schedule for new water rights may be deferred if growth is slower than projected (as occurred between 1999 and 2005), or accelerated if demand increases above projected rates (e.g., new industrial demand develops). Given the rate that new water right applications are processed, it is recommended that the City submit applications for new water rights and pursue the processing of such applications.

4.2.2 Water Supply Sources

The City's water supply system relies exclusively on groundwater supplied by five wells ranging in capacity from approximately 140 gallons per minute (gpm) to 560 gpm. All of the City wells are completed in a sand and gravel aquifer. Bedrock was encountered during drilling of Wells 1 and 2, at 191 and 157 feet below ground surface (bgs) respectively. The City's wells are older (26 to 52 years) but have had very few problems during their operation. There are problems reported with low seasonal (summer) water levels and limited available drawdown. Butterfly valves were installed on the discharge line of several of the City's wells in the late 1990's in order to control drawdown in the wells during pumping. Therefore operation of the wells is not optimized with respect to their associated water rights.

City of Forks Municipal Water Supply Well Details

Well No.	Township, Range, Section and ¼-¼ Section	Screened Interval (ft bgs)	Current Pumping Capacity (gpm; valved back to control drawdown)	Associated Water Right	
				Qi (gpm)	Qa (AF/yr)
1	28/13-4 SW SE	125-135	(not used)	500	504
2	28/13-4 SW SE	110-115	180		
3	28/13-4 SW SE	101-109	140	290*	464
4	28/13-9 NE NW	118-128	350	600	446**
5	28/13-9 NE NW	117-128	560		
			Total:	**1,100**	**950**

* Supplemental to Wells 1 & 2.

** This right also has an additional 504 AF/yr volume that is supplemental to Wells 1 & 2, for a total Qa of 950 AF/yr.

The City has been considering installation of a new water supply well to replace the lost capacity of Well 1, to be able to fully exercise existing water rights, and to diversify the water sources supplying the City. Diversification of water supply sources also increases system reliability and redundancy. Because the existing wells do not fully exercise the existing water rights, a new well could be permitted as additional points of withdrawal under existing water rights. Well siting considerations are discussed later in this chapter.

4.2.3 Water Quality

The Washington State Department of Health (WDOH) water quality database (current as of November 2004 was queried to determine if the City's water system has documented any water quality problems. The quality of the City's water appears to be excellent and there are no concerns with the City's water quality, except:

- In 1985, there were several exceedances of iron and manganese (these are aesthetic concerns, not health concerns);

- In the late 1980s there were several detections of disinfection byproducts in the source water; and,
- Well 1 has experienced hydrogen sulfide concentrations in recent years and is currently not being pumped.

There have been anecdotal reports of saline water in isolated wells of the Forks Prairie area. This area is located too distant from the Pacific Ocean to have any reasonable concern related to saline intrusion. Such reports, along with the hydrogen sulfide in Well 1, is most likely related to deep-seated groundwater flow discharging from bedrock to the unconsolidated sand and gravel aquifers.

4.2.4 Existing and Future System Storage

The City has three above-ground storage tanks with nominal capacities of one million gallons, 750,000 gallons and 150,000 gallons. The 150,000 gallon tank is currently not in use and is being considered for replacement by a larger tank (e.g. one million gallons). The actual working storage capacity is approximately 1.55 million gallons (e.g., due to dead storage), which provides for 2.5 days of storage assuming at the current average daily demand of 0.6 MGD, based on assumptions in Polaris (1999). Although not explicitly stated in the Comprehensive Water System Plan, it is assumed that Polaris (1999) accounted for dead storage in the reservoirs.

Total annual water use in 2004 has not changed significantly from 1999. Therefore, current and projected future storage needs are taken from the 1999 Comprehensive Water System Plan and adjusted assuming no significant change between 1999 and 2005, and assuming future annual demand growth of 1% and 3% (Figure 4-10). The DOH Water System Design Manual has specific requirements and guidelines for storage, as summarized:

- Dead storage – storage needed to provide minimum water pressures; that is, the volume of water (in any reservoir) which is less than approximately 70 feet (30 pounds per square inch [psi]) above the highest service in that pressure zone.
- Standby storage – storage for reliability purposes (e.g., if one or more sources is out of service for a short time); required volume is calculated as follows:

  2 x average day demand minus daily supply capacity of all sources except the largest (but recommended not less than 200 gallons per day per Equivalent Residential Unit (ERU; an ERU is a unit of measure used to equate non-residential water usage to single family residences. For example, if a system has sufficient capacity to serve 100 Equivalent Residential units (ERUs), then it can serve 100 single family houses. Similarly the same system could serve 80 single family residences and one (or more) commercial services that has a water use equivalent to 20 ERUs. For example a school might be expected to use the same amount of water as 20 single family residences. Therefore, this school represents 20 ERUs.)

- Peak flow storage – storage to supply peak demands in excess of supply capacity. Required volume is calculated as follows:

  (Peak hour demand minus capacity of all sources) x 150 minutes

In some cases, peak flow and standby storage, the largest two components, are combined due to economic necessity on the assumption that the likelihood of a source outage and a major fire occurring on the same day is small. DOH requires the fire marshal to formally approve combining these two storages. Ten State Standards indicate only that storage is adequate to meet domestic and fire flow demands (Great Lakes - Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers, 2003).

Based on Polaris (1999), the City of Forks will need new storage by the year 2012 at the earliest (i.e., assuming a 3% demand growth rate). New storage may be deferred significantly into the future based on lower historical annual growth rates (e.g., 1% or less).

4.3 Well Tests

Limited aquifer testing was conducted by Golder staff on May 24 and 25, 2005. The field visits performed by Golder staff are detailed in Appendix 4-A. In order to determine the specific capacity of the wells, each of the City wells was pumped for 30 minutes and the drawdown at the end of this time was measured. Well 5 was pumped for 1 hour in order to determine if there was an impact to the water level in other City wells as a result of pumping in Well 5. There was no drawdown observed in Wells 1, 2 or 3 as a result of pumping in Wells 4 or 5.

City of Forks Wells Specific Capacities

Well	**Pumping Rate** (gpm)	**30-Minute Specific Capacity** (gpm/ft)	**Comments**
1	-	-	Well was not tested. Used as observation well only. (2003-2004 data indicate a specific capacity of ~36 gpm/ft)
2	180	67	
3	140	89	
4	352	30	
5 *	565	-	Water level could not be sounded past 96 feet due to blockage in well.

Following the specific capacity tests, Well 3 was pumped at 140 gpm for approximately 18 hours and the water levels monitored in the other City wells in order to determine aquifer parameters (e.g., transmissivity and storativity; Figures 4-11 through 4-13). Analysis of the Well 3 aquifer test data indicated a leaky aquifer. This is likely the result of recharge being induced from layers above the screened sand and gravel layer. The pumping test analysis indicates that the sand and gravel aquifer unit is highly transmissive, which resulted in a shallow cone of drawdown. The data do not indicate that any hydraulic boundaries (e.g., low permeable or recharge boundaries) were encountered during pumping. The fact that no boundaries were encountered during the constant discharge test of Well 3 is consistent with the very shallow cone of depression observed, where approximately 1.9 feet of drawdown was observed in Well 3 and no drawdown was observed in Wells 5, located 1,600 feet away (Figure 4-14).

The constant rate pumping test data were analyzed using the commercial program *Aqtesolv for Windows* (version 2.12; Duffield, 1998). *Aqtesolv* is an interactive solver which enables the user to readily apply different analytical solutions to derive the key aquifer parameters, and has both manual and automatic curve matching functionality.

For the analysis, the applicability of the Theis confined aquifer method (1935), and the two leaky aquifer methods of Hantush (1955, 1960) were evaluated. The potential for aquifer boundaries to influence the test data were evaluated using both confined and leaky solutions.

The analysis using the Theis method resulted in reasonably good curve fits, with very high transmissivities (in the range of 28,000 to 42,000 ft^2/day). However, such a condition would yield an average hydraulic conductivity of between 1,100 and 1,700 ft/day (based on a saturated thickness of 25 feet). These results are not consistent with the lithologic description of the aquifer material, which are expected to have a lower conductivity.

One cause for the higher than expected transmissivity using the Theis method is the possibility that the overlying sediments contain and can release sufficient water when the well is pumped to effectively reduce the drawdown in the actual aquifer. This is often referred to as a leaky aquifer condition. The Hantush methods are, in essence, variations on the Theis approach, but account for the storage effect of the overlying formation. The two Hantush methods differ in that whereas one solution assumes that the piezometric level in the aquitard remains constant during pumping, the other assumes that drawdown occurs. Comparing the two approached for the test data, we decided that the latter was more appropriate, with the following results:

Assumed Aquifer Parameters

	Distance from pumped well (feet)	**Transmissivity** (ft^2/day)	**Hydraulic conductivity*** (ft/day)	**Storativity**	**β-value****
Well 1	**780**	**9,000**	**360**	**0.005**	**1.25**
Well 2	**330**	**11,700**	**470**	**0.01**	**0.5**
Well 3	**0**	**11,800**	**470**	**-**	**0.1**

* Based on a saturated thickness (b) of 25 feet

** For Hantush (1960), β-values were assumed based on a K':S' factor of between 2 and 2.5 (assuming b' = 50 feet).

Figures 4-11 through 4-13 show the final analytical curve matches for the field data. Following the brief well tests conducted in the City's wells, the pressure transducer used to measure water levels remained in Well 1 to record water level data between May 24 and June 2, 2005. The water level data were then compared to barometric pressure, precipitation and river stage in the Calawah River. Barometric pressure and precipitation data were measured at the Quillayute State Airport (www.ncdc.noaa.gov/oa/ncdc.html). River stage data for the Calawah was obtained from the USGS for a gage near the Highway 101 bridge in Forks (http://waterdata.usgs.gov/wa/nwis/uv?12043000).

There does not appear to be a strong and direct correlation between water level in Well 1 and barometric pressure (Figure 4-15). Such a correlation would indicate a confined aquifer. The pumping test indicated a leaky response, which is consistent with the absence of a discernible correlation of groundwater levels to fluctuations in barometric pressure. The relationship between groundwater levels on one hand, and stream stage and precipitation on the other hand is less clear (Figures 4-16 and 4-17). Groundwater levels dropped significantly over the period monitored. The water level in Well 1 are presumed to show a response to precipitation. Between May 13 and 23, approximately 4.5 inches of rain was recorded at the Quillayute State Airport (Figure 4-16). Between May 24 and May 30, not more than a trace of rain was recorded at the Quillayute State Airport and the water level in Well 1 declined approximately 0.5 feet. Unfortunately, water level data from Well 1 are not available before May 24, and therefore the aquifer's response to precipitation cannot be fully determined. However, it appears that the water level declines when precipitation is not recharging groundwater. The effect of Well 2 pumping is clearly seen on the water level in Well 1 (Figure 4-15). It is assumed that the drop in water level is related to environmental conditions (e.g., precipitation) and not to pumping of Well 2 because the dropping trend does not stabilize between the pumping cycles of Well 2.

The water level in Well 1 does not show a strong and direct correlation to stage in the Calawah River. between May 24 and June 2, 2005, the water level in Well 1 declined approximately 0.75 feet (Figure 4-17). During this same period, the Calawah River stage declined approximately 1.5 feet. There is insufficient data at this time to determine the exact hydraulic relationship between the Calawah River and the aquifer beneath Forks Prairie, but it appears that the aquifer does respond directly to changes in river stage. Instead both river stage and aquifer water level decline when precipitation is not occurring in the area.

4.4 Wellhead Protection

A Wellhead Protection Program consists of delineating capture zones of wells, conducting an inventory of possible contaminant sites in the general area, preparing a qualitative assessment of the potential impact of these to the water supply, and implementing appropriate ordinances for the adequate protection of drinking water supplies. In this report, a three dimensional steady state groundwater model is presented that simulates captures zones of the drinking water wells of the City of Forks, and a contaminant inventory was commissioned. (The contaminant inventory, Appendix 4-B, and is provided under separate cover to the City of Forks.)

4.4.1 Forks Prairie Groundwater Model

A numerical groundwater flow model of the area to assist with the wellhead protection evaluation. The model uses the USGS code *MODFLOW* to simulate groundwater flow in the alluvial and glacial outwash sediments. *MODFLOW* uses a finite-difference method to solve the complex groundwater flow equation in three dimensions. The particle tracking code *MODPATH* was used with the flow model to simulate the capture potential of the City's wells.

4.4.1.1 Model Construction

The numerical model was based on the current conceptual understanding of the hydrologic and hydrogeologic system. The main components of the system are:

- Aquifer properties;
- Surface water bodies;
- Recharge; and,
- Pumping.

Model Domain and Grid

The model grid consists of cells varying in size from 50 foot square (in the general vicinity of the wells) to 200 foot square at the model's perimeter (Figure 4-18). This grid system allows the model to predict flows, gradients and velocities with sufficient accuracy in the immediate wellfield areas. The aquifer system was divided into two discrete layers - an upper layer (representing the overlying, partially saturated material) and a lower layer (representing the true aquifer).

The top of the model was established as coinciding with land surface; Golder developed this surface from USGS DEM files (30-meter resolution) which were interpolated to the final model grid. The base of the model was set to coincide with the top of the bedrock, which for this project was assumed to be relatively impermeable.

Aquifer and Aquitard Properties

The model base was assumed to slope generally east to west at roughly the same gradient as the land surface (Figures 4-19 and 4-20). The depth also increases from the north and south edges to the center of the model. The hydraulic properties assigned to the aquifer and overlying aquitard based on the results of the aquifer testing performed in May 2005 (see Section 4-3). These parameter values were varied during model construction and calibration

- Upper layer: K_h = 20 ft/day; K_v = 10 ft/day
- Lower layer: K_h = 350 ft/day; b = 25 feet

For the purpose of performing transport runs for capture zone assessment, uniform effective porosities of 0.15 and 0.2 we assigned to layers 1 and 2, respectively. At this stage, the model was established to be used in steady-state mode; therefore, no specific storage parameters were assigned for these layers.

Recharge

Annual precipitation in the valley is typically over 100 inches. A uniform recharge rate of 54 inches per year (0.0123 ft/day) was applied to the top of the model to represent recharge derived from precipitation and run-off that enters the subsurface at the valley edges.

Subsurface Flow

As the model boundaries do not coincide with the true aquifer limits at the up and down-gradient extents, we used the Constant Head function in MODFLOW to allow groundwater to enter and exit. These boundaries were located at sufficient distances from the wellfield area that future pumping would not cause a significant change in the fluxes across these boundaries.

Surface Water

The Calawah River flows east to west through the valley, and includes a meandering reach just west of the wellfields. The river is suspected to receive considerable discharge from the aquifer system in the area. Although only one USGS river gage exists in the region, the baseflow component to the river flow is likely in the order of 50 cfs. Therefore, the river was considered to be a major sink for the groundwater in the model.

The river was incorporated into the model using the head-dependent *RIVER* module. The river stage (which remains unchanged in response to applied stresses) was set at the approximate land elevation based on the USGS topographic maps and DEM data. The river bed for each cell was assumed to be 5 feet below the stage level, and a river bed conductance value of 25 sq. ft/day per linear foot of river reach was assumed to be reasonable to represent the hydraulic effects of the relatively granular surficial soils.

Towards the southwest model boundary, the Fork Prairie terminates topographically; this feature is marked by a line of springs which discharge groundwater at an unknown rate. We represented this in the model using a line of *DRAIN* cells that allow water to flow out of the upper layer.

The net discharge from the river and springs in the calibrated model were 56 cfs and 6 cfs, respectively.

Pumping
The average pumping rates assigned the wells were equal to the average annual water right limits (assuming continuous, year-round pumping) distributed among the wells: 156 gpm (for Wells 2 & 3) and 138 gpm (for Wells 4 & 5). Well 1 is inactive and was not included in the model. For the baseline condition, we set pumping for these wells equal to zero; this was done because the best field-measured water levels for these wells were measured with all wells non-pumping. All pumping fluxes were assigned to model layer 2.

4.4.1.2 Model Results

Figure 4-2 shows the modeled baseline flow field in the aquifer (layer 2). Although groundwater is generally from the east to west through the valley, the piezometric contour pattern indicates the major sink effect of the river. The average potentiometric gradient in the wellfield vicinity is about 0.007.

Figure 4-21 also shows the calibration results for the target wells. The box-plots indicate the difference between the model-calculated and the field observed water levels. These residuals are between 0.2 and 3.5 feet at the wellfield wells, which is generally acceptable for a model of this magnitude. The calibration for the two, upgradient private wells are less close. However, some uncertainty exists regarding the reliability of the measured water level elevations.

The model was run to steady-state with the wellfield wells pumping at their average annual water right rates; Figure 4-22 shows the resulting groundwater flow field for the main aquifer. The piezometric contours differ from those for the calibration baseline set in the vicinity of the wells, but the difference is fairly minor. The maximum water level difference between the two conditions is about 2.5 feet. The actual drawdown in the wells will be greater than this because of the well inefficiency effects and the fact that the modeling method averages the water level in the cell containing the well across the cell width (50 feet).

Golder then used *MODPATH* to determine the time-based capture zones for the wells under the new flow field conditions. Figures 4-23 through 4-25 show these capture zones for 6 months, one year and 5 years, respectively. The capture zones have a distinctly long and narrow shape, which is typical for well pumping from a relatively highly transmissive aquifer at low rates.

The 10-year time-of-travel zone was not determined because it extended beyond the model boundary. The model did not extend further east because of lack of information on the aquifer thickness and properties, and recharge areas including points of connection with streams.

Some of the water intercepted by the wells will be derived locally from the overlying (aquitard) sediments. The model is unable to determine the relative contribution from each layer.

4.4.2 Contaminant Inventory

Golder contracted Environmental Data Resources, Inc. (EDR) to produce a contaminant inventory of the Forks area. This report uses available environmental databases and the data have not been verified. The Contaminant Inventory was centered on Section 13 of Township 28N, Range 13W, and has a coverage radius of three miles. The survey was dated May 15, 2005, and included in Appendix 4-B of this report.

Database Findings

The following summarizes the findings:

- Six facilities were found to be listed on the EPA's RCRAInfo database. This database includes sites that are known to generate, transport, store, treat and/or dispose of hazardous materials.
- One State Hazardous Waste (or priority) Site was identified. This designation indicates that the site has planned remedial action using state funds and potentially responsible parties.
- The report identified the presence of three (3) leaking underground storage tank (LUST) sites in the coverage area, and a further ten (10) underground storage tank (UST) sites in the survey area. USTs are regulated under RCRA, and the data are stored in Ecology's LUST and UST Site/Tank Reports.
- Two sites were identified as having entered into the Voluntary Cleanup Program (VCP), or as having some level of remedial action.
- The FINDS (Facility Index System) contains 21 sites in the survey area. This database lists sites which have activities that only could pose a risk to the environment, and provides sources for additional information.
- One mine site, listed in the Mines Master Index File, exists in the survey area.
- Two sites were found under the ICR list; these sites have undergone remedial action outside the regulatory oversight programs. (Both sites were also listed in the LUST and UST databases). Two sites were also listed in the Brownfields database, both of which were also in the UST list.

*Note - many of the sites were listed in more than one of the databases covered by the survey.

Potential Impact to Wellfield

The hazardous substances reported for all listed sites are petroleum products – gasoline, diesel and oil. These products contain chemical constituents (such as benzene) that are known to be detrimental to the environment and human health if released. Some of these chemicals are relatively mobile in the subsurface, and are readily dissolved in groundwater. Several of the listed sites are located upgradient from the City's wells.

Only one site should be considered for further assessment; this is the WADNR Headquarters facility. The WADNR facility is located between the well clusters, and also operated USTs which appear to have released gasoline products to the soil. The LUST database indicates that this site was cleaned up and some of the USTs have been removed.

None of the remaining sites have known chemical releases. If future releases do occur, the chemicals would need to travel vertically through as much as 75 feet of unsaturated zone before encountering the water table. The migration rate is difficult to estimate without field testing. Although upper soils are heterogeneous with lithologies ranging in texture from clay to sand, the infiltration rate is expected to be relatively high. During the migration, these chemicals typically degrade to less toxic products, thereby reducing their threat.

4.5 Future Well Siting

The most limiting factors in siting a new well are anticipated to be the existence of an aquifer at a particular site (versus encountering bedrock), and available drawdown (e.g., the water level in the well). Consideration should also be given to future zoning implications for wellhead protection purposes.

Bedrock irregularities may pose difficulty in siting wells. The marine sedimentary and igneous rocks that comprise the bedrock in the Forks area generally cannot support productive water wells (Golder, 2005). Depth to bedrock is a critical factor in siting future wells. If bedrock is encountered at a shallow depth, there may been insufficient drawdown to allow a municipal well to be installed. Cross-sections in hydrogeologic report contained in the most recent Comprehensive Water System Plan (Polaris, 1999) are highly speculative. A smooth U-shaped bedrock valley is unlikely given the degree of topographic relief present in the bedrock foothills adjacent to the valleys. The subsurface bedrock could have significant topographic relief.

Hydrogeologic cross-sections of the Quillayute Prairie/Three Rivers/Forks Prairie area were prepared using well logs on file with the Washington State Department of Ecology (Ecology). In addition to information provided by well logs, the Washington Department of Natural Resources (WDNR) 1:100,000 surficial geology was used to determine the location of geologic units (e.g., alluvium, till, outwash, bedrock etc). The hydrogeologic cross-sections indicate a basal gravel unit above the bedrock (Figures 4-3 through 4-6). Existing well logs on file at Ecology for wells installed north of the Calawah River indicate that bedrock is likely shallow in the area (40 to 100 feet). Department of Ecology's well log database indicates that at least four dry wells were installed north of City:

Dry Wells on North Side of Calawah River

Well Location (T/R-S ¼/¼)	**Total Depth of Borehole** (ft bgs)	**Material Encountered**
29/13-29 SW/SE	225	Shale
29/13-32	138	Shale
29/13-32 NE/NE	50	Clay
29/13-32 SW/SE	104	Shale

Our assessment is that there is more risk drilling a well north of the City. Therefore, we recommend well sites be considered near the middle of the Forks prairie, not too far from the location of Calawah Way. Moving north or south from the center of the prairie may encounter a shallower depth of aquifer material above the bedrock, thus limiting available drawdown. Areas east of town in T 28 N, R 13 W may be possible locations:

- SW Sec 3
- NW ¼ of the NW ¼ of Sec 10
- NE ¼ of the NE ¼, and the SE ¼ of the NE ¼ of Sec 9

The cost of a geophysical survey should be investigated for siting a new well to increase the probability of successfully installing a productive well. Potential methods include: time domain/seismic refraction to find depth to bedrock, resistivity to locate gravel layers.

The high transmissivity of the aquifer suggests that interference between wells should not be a major consideration in well siting. Figure 4-14 predicts drawdown interference from a well pumping 140 gpm on the order of half a foot at a distance of 100 feet.

4.6 Conclusions and General Recommendations

Installing a new well will diversify the existing array of municipal water supply wells and improve system redundancy and reliability. It will also allow the City to more fully exercise existing water rights. Such a well could be permitted with water rights by adding it as an additional point of withdrawal to existing water rights.

Current demand estimates (Polaris, 1999) indicates that new water rights will be needed in the near future (e.g., within five years). These estimates may be conservative, and new water rights may not be needed for an extended period of time, depending on water demand growth rates (e.g., new industrial demand). Applications should be submitted now for future water rights.

In order to prevent contamination of groundwater north of the river, it is recommended that the Grafstrom well in the Forks Industrial Park be abandoned in accordance with WAC 173-160-381. If other unused wells are identified within the City's service area, they should be properly abandoned as well.

The current operation of the wells consists of pumps whose flow is maintained significantly below their designed rates by valves. This is expected to create an unnecessary energy bill. Simple energy cost auditing may indicate significant cost savings through the purpose of appropriately sized submersible pumps.

Given the age of the wells, a video inspection should be conducted on any of the City wells in which pumps are pulled for maintenance. A video inspection of Well 2 from 2004 indicated that the screen was in fairly good shape. However, there appeared to be staining around a casing joint, perhaps indicating that one of the welds might be compromised. Unfortunately the camera could only recorded downhole views (not sideways) and no depth information was provided on the video in order to determine the depth of the casing joint.

Before groundwater development occurs at the Quillayute Airport, a hydrogeologic investigation should be conducted. In order to do this, a close working relationship with the citizens living near the airport should be established to facilitate access to private wells. This work could be conducted in conjunction with the Army Corps of Engineers, who are currently conducting contamination cleanup efforts in the area. A hydrogeologic investigation of this area would entail gathering well logs, collecting water level measurements, collecting samples for water quality analysis, perhaps limited pumping tests could be conducted on existing wells.